Numerical Circulation Modeling as a Tool for Harmful Algae Bloom Research and Prediction

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Introduction

In this paper, I discuss the use of three-dimensional (3-D) numerical circulation modeling for studies of Harmful Algae Blooms (HABs). Puget Sound is being modeled this way as part of the Puget Sound Regional Synthesis Model (PRISM) at the University of Washington (UW). I will show some early model results, concentrating on the salinity field, and discuss model capabilities in relation to factors important to blooms. While true bloom prediction may be more than a decade in the future, a better understanding of what forces near-surface temperature, stratification, and horizontal stirring in the Sound is a reasonable near-term goal. Observational data collected by bloom researchers will be crucial to this effort.

Circulation Modeling

The PRISM Project

PRISM is a multi-disciplinary project, funded internally by the University of Washington, to coordinate and synthesize research, education, and outreach on issues affecting the Puget Sound basin (land, air, water, etc.). Related talks at this conference are being given by J. Richey and M. Kawase.

Puget Sound Circulation Modeling

Mitsuhiro Kawase, also a UW physical oceanographer, has initiated the circulation modeling. The Princeton Ocean Model (POM) is used, as it is by many coastal end estuarine researchers around the world. This time-dependent 3-D model allows realistic bathymetry and has a turbulent mixing parameterization. The initial simulations span more than a year of model time, and were forced by tide height at Admiralty Inlet and freshwater inflow from eight rivers, using stream flow data for October 1990–1991. Future simulations will include realistic wind stress and surface heating, available from a predictive model being run at UW Atmospheric Sciences. Ocean inflow properties from the Strait of Juan de Fuca will remain unknown until a monitoring-buoy array is set up there.

The ability to model 3-D circulation in estuaries is a recent development in Physical Oceanography. In the past, physical lab models were the only way to approach system-wide questions. Such physical models range from the three-meter Puget Sound model at UW to much larger models of San Francisco, Chesapeake, and other bays, which fill large buildings.

Model Results

The model surface salinity field during a spring tide, after a period of strong river runoff, is shown in Figure 1. Note the gradual decrease of salinity from head to mouth, most pronounced near rivers, especially the Skagit. The model horizontal resolution is 600 m (E/W) by 900 m (N/S). The year-long cycle of Skagit inflow used by the model is shown in Figure 2. It may also be seen in Figure 1 that Admiralty Inlet and Tacoma Narrows are sites of vertical mixing, bringing up saltier water from depth (Seim and Gregg, 1991, 1994). Vertical profiles of salinity from Whidbey Basin are shown in Figure 3 for times of low and high river flow. The model makes calculations on 12 vertical levels distributed evenly over the local water depth. This strategy gives greater vertical resolution in shallow areas. Comparing to analogous profiles (not shown here) from the Washington State Department. of Ecology 1993–1994 (Newton et al., 1997) an obvious feature missing is the mixed layer near the surface. This is the result of the lack of wind forcing, which promotes mixing in the top few meters of the water column (Price et al., 1986).

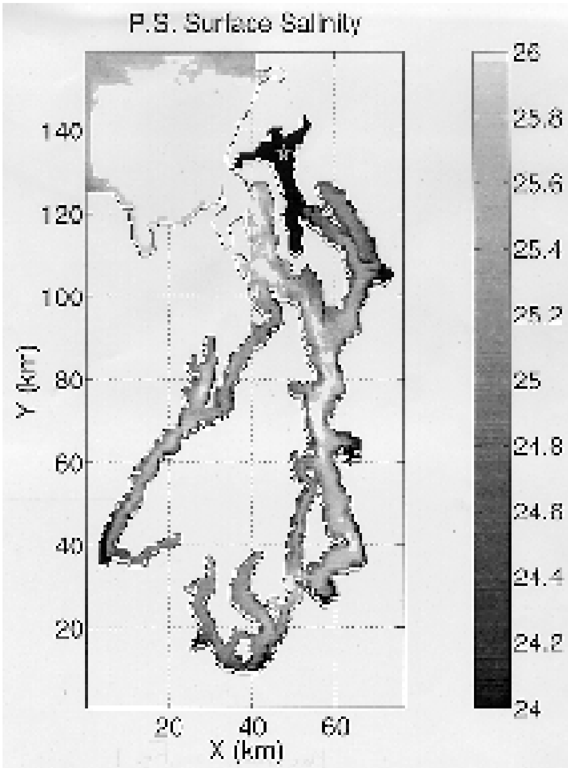

Figure 1. Model surface salinity after a time of high runoff (time shown as a star in Figure 2).

Bloom Scales and Model Scales

HABs require specific (and often not well known) conditions to occur (Steidinger, 1975; Anderson, 1997), relating to pre-conditioning, temperature, nutrients, etc. Circulation patterns such as internal waves, gravity currents, fronts, and tidal stirring can transport and concentrate the algae (Franks 1992, 1997). For *Heterosigma* in Puget Sound, certain temperature and stratification values appear to be key (Laurie Connell, pers. comm., and this volume). Using Connell's bloom observations in Rich Passage (just S. of Bainbridge Island) on July 17, 1997 as a benchmark, we may propose scales at which the model must be able to make predictions:

1) HAB inception may require water warmer than a certain (strain specific) level; model temperature predictions should be within 1 _C in the mixed layer.

2) Optimum mixed layer depth for bloom maintenance appeared to be 7–10 m, so one needs vertical model resolution of at least one meter in the euphotic zone.

3) Blooms may occur over time scales of a day, so resolution of the tidal cycle is necessary (this is essential to the estimation of turbulent mixing as well).

4) Horizontal advection can readily move bloom patches over the tidal excursion in a single tidal cycle. For fish growers, the presence of bloom conditions at a pen location becomes important in a few hours.

Implications

The PRISM circulation modeling effort should be able to give realistic stratification, temperature, and tidal-eddy advection fields in the near future, at the coarse resolution of the results presented above. Finer-scale features, such as individual bays, will require nested modeling. While the model should be able to give statistically realistic results, predictions of fields on individual days is a much harder task. Significant work will be to (1) include atmospheric forcing, and (2) make comparisons with the statistics and patterns of historical hydrographic data, especially that from Ecology's Ambient Monitoring program. Correlation of river flow, weather, and tidal stage with stratification events may be of use to growers. Because of the importance of atmospheric forcing, it will remain impossible to predict water surface conditions any farther into the future than the weather (2–5 days). Future work will involve nutrient balances and eventually algae modeling.

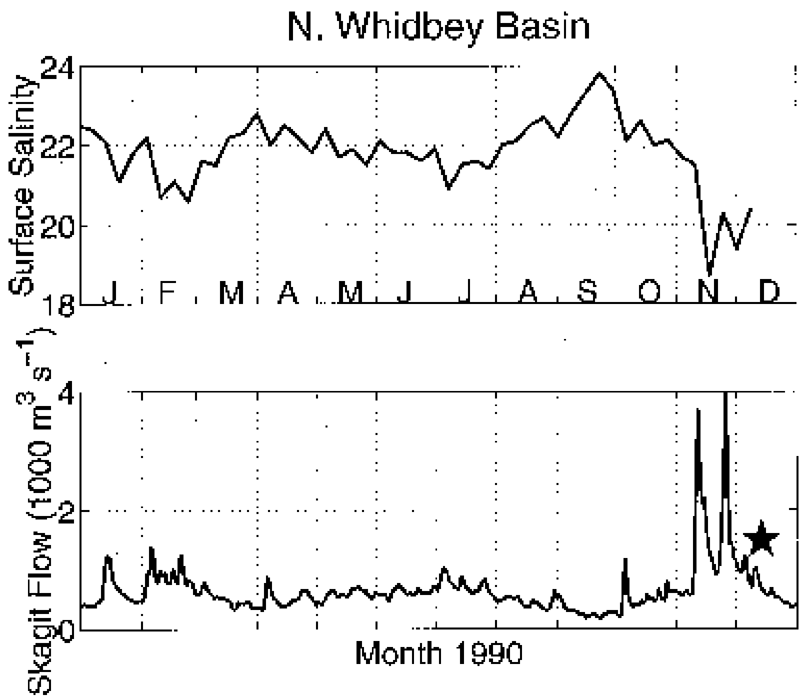

Figure 2. Upper panel: model surface salinity versus time at a point in N. Whidbey Basin (shown by a star in Figure 1). Lower panel: Skagit River volume flow used to force the model (along with seven other rivers). (The river data actually span October 1990 to October 1991.)

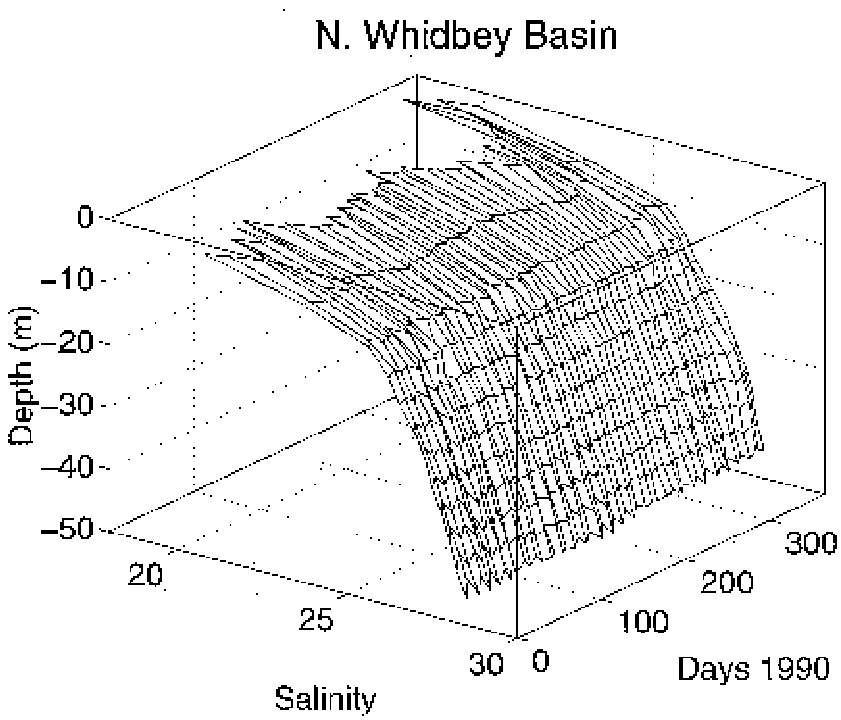

Figure 3. Salinity versus depth and time at the same location in N. Whidbey Basin. The deep salinity changes little; most changes in stratification are due to river-forced changes in surface salinity.

Acknowledgments

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